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Hampton, Virginia 23665

REMOTE MONITORING OF A THERMAL PLUME

By Chin Y. Kuo,[1] A.M. ASCE and Theodore A. Talay[2]

INTRODUCTION

NASA is investigating the potential uses of remote sensing in monitoring industrial ocean dumps, sediment plumes, and thermal discharges in the water environment. Aircraft-borne multispectral scanners and photographic systems have provided synoptic coverages of such discharges entering rivers, estuaries, and coastal zone waters. Repetitive overflights with such sensors, especially in tidally dominated, unsteady flow situations, yield temporal distributions that provide an insight into the discharge dynamics. Comparison of sequential coverages of the same area may show the surface temporal response of the discharge to stresses in the environment and provide public officials a monitoring capability without the need of large surface surveys.

This paper discusses a remote-sensing experiment conducted on May 17, 1977, over the Surry nuclear power station on the James River, Virginia. Isotherms of the thermal plume from the power station were derived from remotely sensed data and compared with in situ water temperature measurements provided by the Virginia Electric and Power Company, VEPCO. The results of this study were also qualitatively compared with those from other previous studies under comparable conditions of the power station's operation and the ambient flow. These studies included the hydraulic model prediction carried out by Pritchard and Carpenter for VEPCO (1) and the 5-year in situ monitoring program based on boat surveys conducted by the Virginia Institute of Marine Science, VIMS (2).

EXPERIMENT

On May 17, 1977, a remote sensing experiment was conducted by NASA Langley Research Center, on the James River, Virginia, as a cooperative effort involving NASA, the Virginia State Water Control Board, the U.S. Army Corps of Engineers, and Old Dominion University. The main aircraft used was a P3-A, four-engine, low wing type staged from the Langley Research Center, Hampton, Virginia. Onboard the aircraft was an 11-band multispectral scanner, including a thermal band, and a Zeiss aerial mapping camera. The area overflown ranged from Newport News to Hopewell, Virginia, and included the Surry nuclear power station near Hog Island, Virginia (fig. 1). Sixteen overflights of the Surry thermal discharge were made at 3300 m altitude starting at 2.0 hours after low tide to

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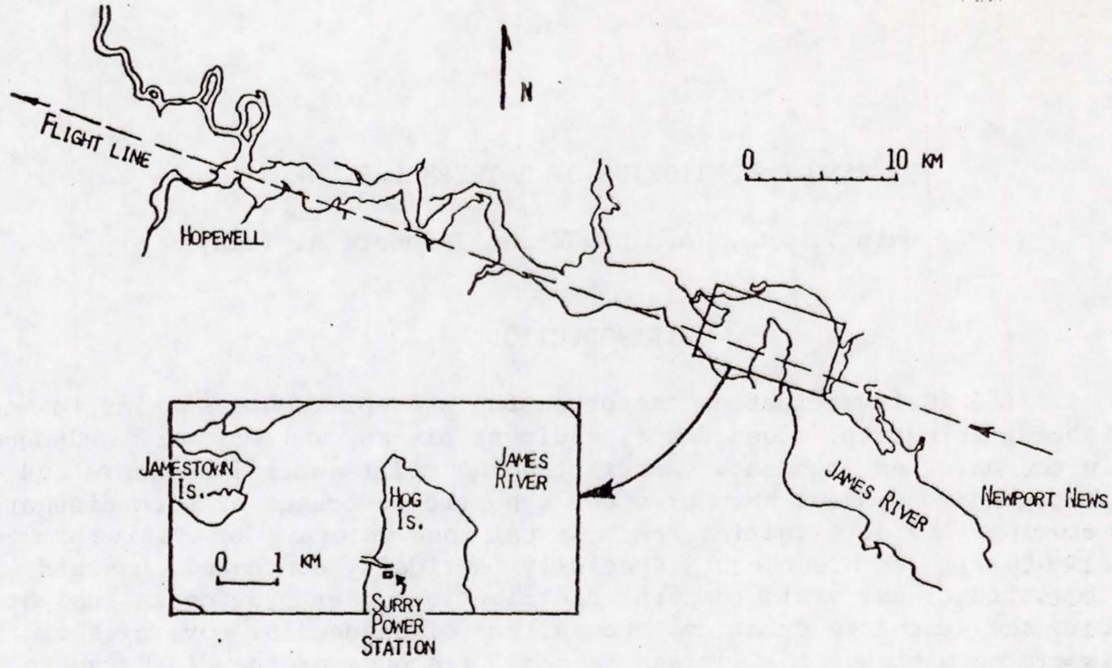


FIGURE 1. - AREA OVERFLOWN BY REMOTE SENSING MISSION OF MAY 17, 1977.

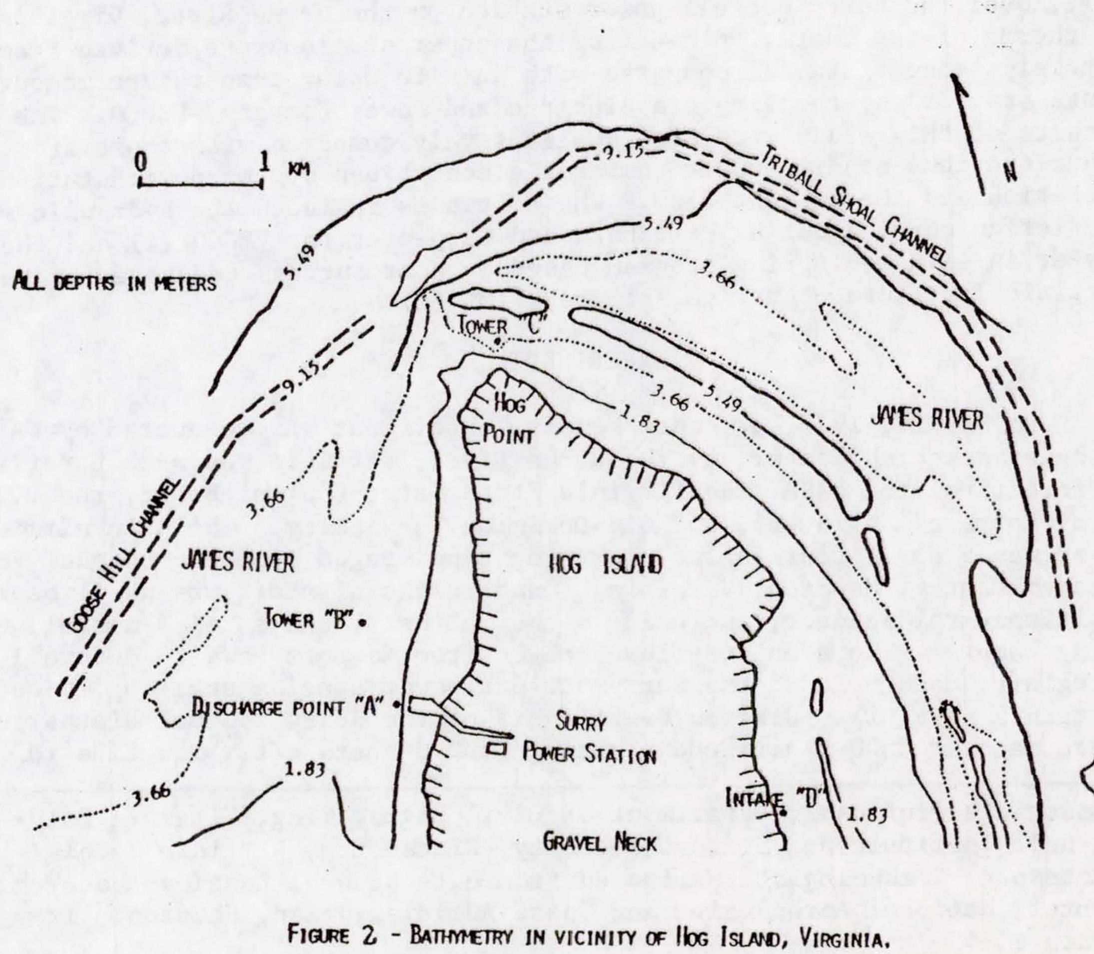


FIGURE 2 - BATHYMETRY IN VICINITY OF HOG ISLAND, VIRGINIA.

0.9 hour before the following low tide at Hog Island. A considerable portion of one tidal cycle was, thus, observed in these overflights. Six of these overflights were chosen for use in the present study. Two isotherm maps are included in this paper.

TEST CONDITIONS

The sky conditions on May 17, 1977, were generally clear with scattered high stratus clouds above 3300 m and a few scattered low cumulus clouds over land areas. A moderate haze was present and air temperatures rose to about 30°C by late afternoon. Winds were very light (less than 2-3 m/sec) and variable with a westerly direction for the morning overflights and a general northeast direction for the afternoon overflights.

Very low riverflow conditions existed for the James River on May 17. The combined flow from the James and Appomattox Rivers at Hopewell was 96 CMS compared to an annual average of 255 CMS (3).

Tides and currents have a marked effect on thermal plume dynamics. On the day of the experiment, high tide was 0.58 m above the mean low water, and the maximum ebb and flood currents were 70 cm/sec and 40 cm/sec, respectively. In general, the times of high and low tides do not correspond to the times of high or low slack water.

The bathymetry of the region of Hog Island influences the resultant flow field. Figure 2 shows the bathymetry in 1.83 m contour intervals. Features include a gently sloping plain area to the west, or upstream, of Hog Island which terminates at a main shipping channel represented by the dashed lines. Near Hog Point, the channel divides with a shallow channel close to Hog Island and a deeper shipping channel further north. These channel features continue downstream of Hog Island.

ANALYSIS

In a previous report (4), the influence of tides and riverflow on the near-field discharge dynamics of the Surry thermal plume was discussed based on a set of infrared aerial photographs taken on the day of the experiment. In this paper, thermal mappings for the entire flow field are presented. The dynamics of the plume are related to tidal, riverflow, and bathymetric features.

In the thermal band, the multispectral scanner senses radiation in the 7,900 - 11,600 manometer wavelength range. Radiance data are recorded on a line-by-line basis perpendicular to the flight track. Each of the 800 elements or pixels comprising a line of data represents a ground area of 8 m by 8 m. This also represents the resolution of the scanner at 3300 m altitude. The radiance data were related to temperatures by statistical linear regression analysis using both onboard scanner calibration values and in-situ temperature data taken by boats in the James River on the day of the experiment. The resultant linear regression equations were then utilized to convert the scene-wide radiance field into a thermal map, one map for each of the six overflights of the Hog Island area. The mappings were coded to show 1°C increments of temperature in different colors (or symbol tone shadings for this report). Areas away from the thermal plume were arbitrarily classified as ambient James River waters. The plume waters then appear as excess temperatures in 1°C increments.

Table 1 shows the comparison between the results acquired from the

remote-sensing experiment and from the in situ measurements provided by VEPCO. The comparison was for four locations, intake, discharge point, Tower C near the Hog Point, and Tower B near the discharge canal (refer to fig. 2). The comparison was considered to be fair to good. Remotely sensed data for Tower C were consistently lower than the in situ data. The reasons are not well known. This could be attributed to the significant vertical thermal gradient since the in situ sensor was placed one meter below the water surface and the remote sensing data referred to water surface temperature. It could be also due to the complexity of the bathymetry, flow pattern, and mixing processes involving two water bodies of different temperature and salinity.

For the 9 a.m. (e.d.t.) overflight, figure 3 shows the thermal conditions near low slack water as evidenced by the undeflected jet from the discharge canal entering the James River. The main body of the thermal plume is seen to extend from the discharge point to an area well downstream of Hog Point. Except for small pools near the discharge, the temperature excess for the plume does not exceed 2°C. The plume follows the nearshore areas of the upriver side of Hog Island with warmer waters nearer the shore. Near Hog Point, the plume enters the shallow channel area previously described and is seen to follow this basic channel feature downriver until it disappears into the ambient waters. This isotherm map was qualitatively compared with the in situ survey made by VIMS on August 22, 1975 (fig. 4) and the results of the hydraulic model study (fig. 5). Both comparisons were under comparable conditions in terms of plant operation, river flow, and tidal hour. The comparisons were favorable for the dynamic behavior and spreading of the plume. Figure 5 shows the results of hydraulic model study with river flow at Richmond of 57 CMS and 170 CMS, respectively, which brackets the 80 CMS (at Richmond) on the day of the remote sensing experiment. The hydraulic model study showed higher excessive temperatures in the plume than those data from the remotely sensed and in situ surveys. Distortion effects of the hydraulic model had strong influence on the initial dilution and mixing of the thermal plume near the discharge point.

At 3 p.m. (e.d.t.), an ebb condition existed as evidenced by the downriver deflection of the discharge jet (fig. 6). Warm waters are seen to be present downriver of Hog Point. It is not known whether the expanse of warm waters northeast of Hog Point near the corner of the map represents part of the Surry plume that has entered the main shipping channel, or represents warm waters derived from solar heating over shallow water areas. The solar heating effect is evidenced by the warm temperatures outlining Hog Island. The comparison between this isotherm map with the in situ survey of August 6, 1975 (fig.7) was again quite favorable in terms of plume trajectory in the near field, temperature distribution upstream and downstream of the discharge canal.

CONCLUDING REMARKS

Remote sensing of thermal discharges provides both synoptic and temporal coverages not readily available by other means. The quantitative thermal mappings of the Surry nuclear power station discharge, clearly demonstrate the dynamical nature of the plume as it responds to the combined riverflow--tidal conditions. Bathymetric features also control the fate of thermal waters. For the cases presented, excess temperatures in the plume waters did not exceed 2°C for the most part, but were traceable over a considerable expanse. Comparison among the

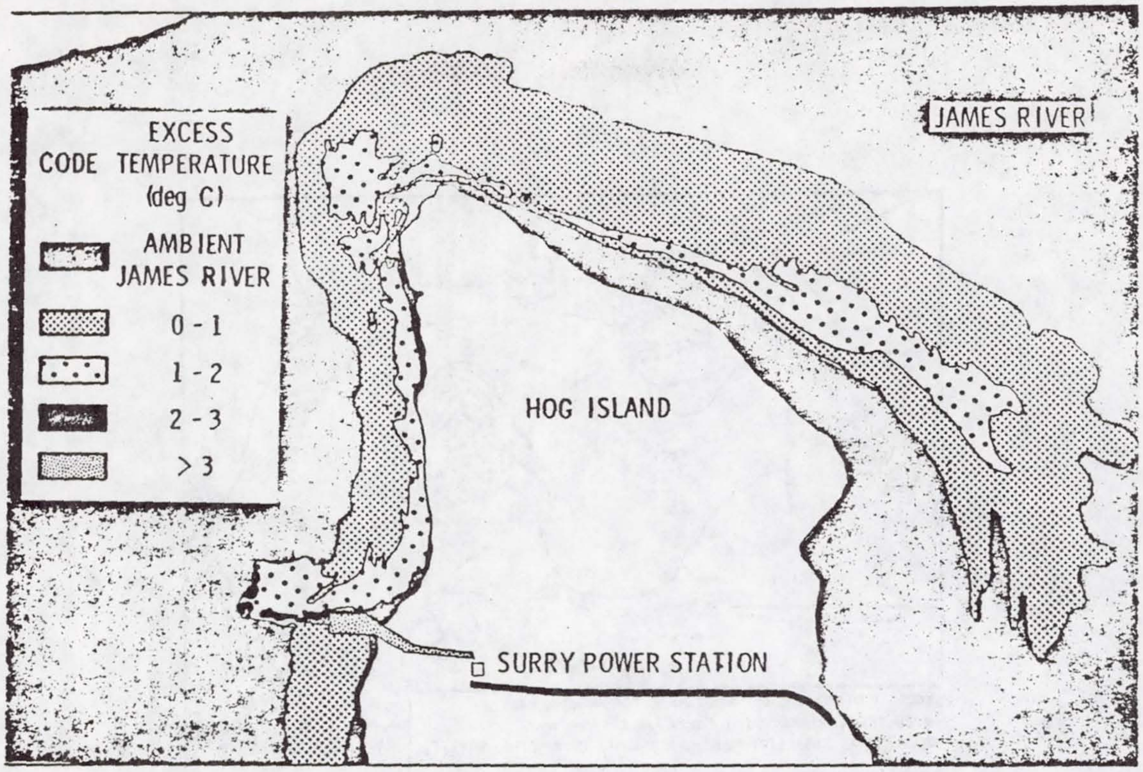


FIGURE 3. - SURRY NUCLEAR POWER STATION THERMAL PLUME - MAY 17, 1977 - 9 A.M. E.D.T.

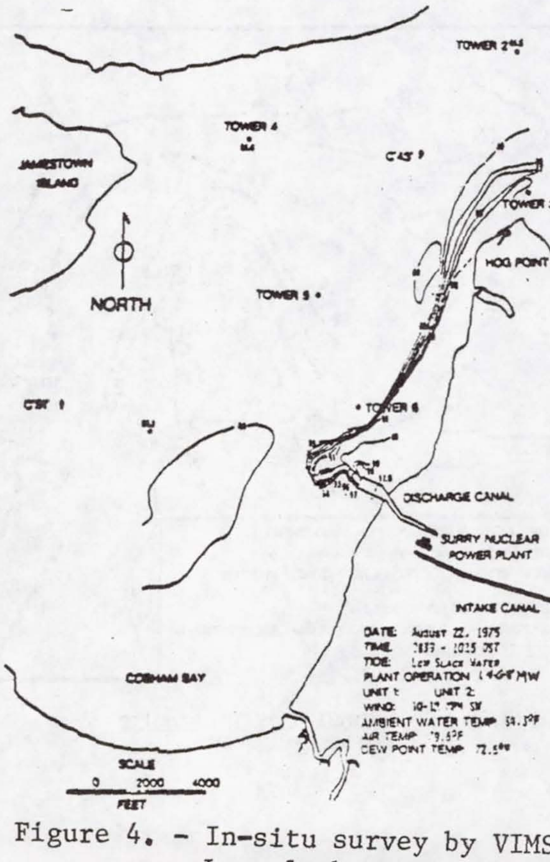
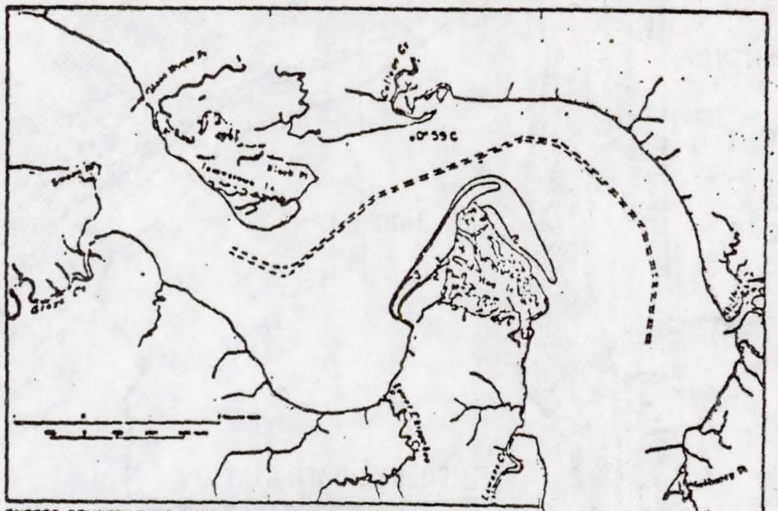
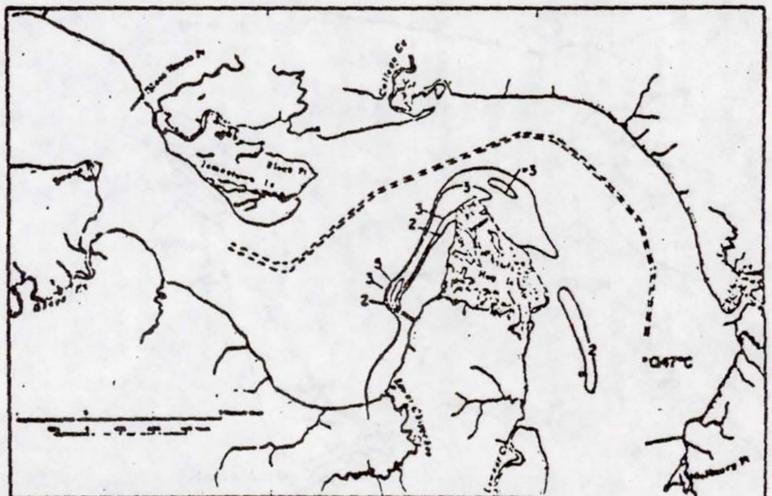


Figure 4. - In-situ survey by VIMS
Low slack water, 1975



EXCESS TEMPERATURE DISTRIBUTION, °C, FOR AN AMBIENT WATER TEMPERATURE OF 26.6°C/80°F AND A 5 MPH WIND VELOCITY, FOR 2 UNITS (TOTAL REJECTED HEAT = 12×10^9 BTU · HR^{-1})

(INTERPOLATED FROM OBSERVED DISTRIBUTION CORRECTED TO ENVIRONMENTAL SURFACE HEAT EXCHANGE CONDITIONS)
RIVER FLOW - 2000 CFS AT RICHMOND
TIDAL HOUR - 6



EXCESS TEMPERATURE DISTRIBUTION, °C, FOR AN AMBIENT WATER TEMPERATURE OF 26.6°C/80°F AND A 5 MPH WIND VELOCITY, FOR 2 UNITS (TOTAL REJECTED HEAT = 12×10^9 BTU · HR^{-1})

(INTERPOLATED FROM OBSERVED DISTRIBUTION CORRECTED TO ENVIRONMENTAL SURFACE HEAT EXCHANGE CONDITIONS)
RIVER FLOW - 6000 CFS AT RICHMOND
TIDAL HOUR - 6

FIGURE 5. - HYDRAULIC MODEL STUDIES FOR VEPCO

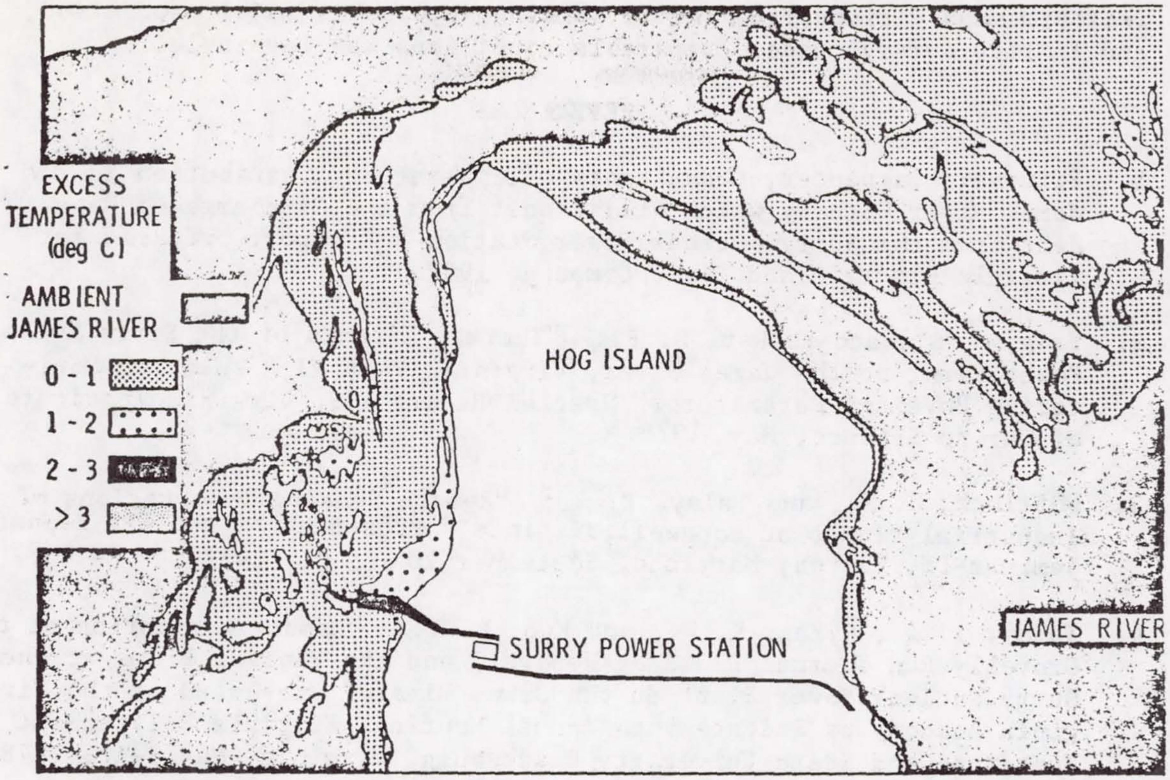


FIGURE 6. - SURRY NUCLEAR POWER STATION THERMAL PLUME - MAY 17, 1977 - 3 P.M. E.D.T.

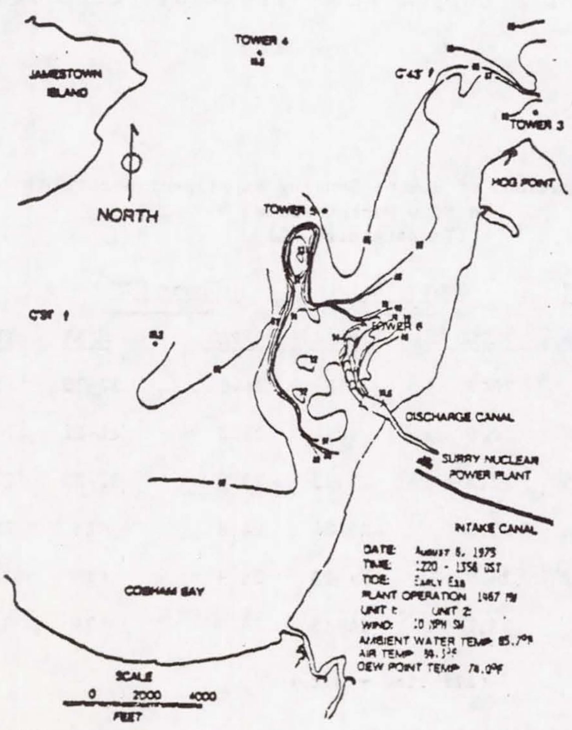


Figure 7. - In-situ survey by VIMS
Early ebb, 1975

isotherm maps derived from remote sensing, hydraulic model prediction, and in situ surveys under comparable conditions was favorable.

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Table 1. Comparison of Remote Sensing Experiment and VEPCO In Situ Measurements (Temperatures °C)

	Discharge Pt. "A"		Tower "B"		Tower "C"		Intake "D"	
Time	VEPCO	NASA	VEPCO	NASA	VEPCO	NASA	VEPCO	NASA
9 a.m.	27.3	>24	20.9	<21	24.6	22-23	19.7	<21
10 a.m.	27.5	>24	20.8	<21	24.3	21-22	20.4	<21
11 a.m.	27.6	24-25	22.1	22-23	23.8	22-23	21.4	<22
3 p.m.	29.1	25-26	25.3	23-24	24.8	<23	22.3	<23
4 p.m.	29.6	26-27	24.9	24-25	24.9	<24	23.4	<24
5 p.m.	30.2	>27	23.2	24-25	24.8	<24	23.7	<24

(all time e.d.t.)

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16. Abstract
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